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Renewable energy resources for electricity generation in Sudan

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Abstract

Electricity reaches only about 30% of Sudan's more than 40 M population; this mainly in urban areas. Hence, a major problem for rural people is the inadequate supply of power for lighting, heating, cooking, cooling, water pumping, radio or TV communications and security services. Petroleum product supplies, including diesel, kerosene and LPG are irregular and often subject to sudden price increases. Because of the inadequate supply of these fuels, women trek great distances into the forest to collect fuelwood, charcoal and biomass residues from animal and agriculture, account for more than half of total energy consumption. Most of this is utilised for cooking and heating water in rural and semi urban areas and by the urban poor. It is a need to provide alternative renewable energy sources to enhance women's participation in, and benefit from development. Household energy was the first energy sector that paid explicit attention to women and their energy needs. The contribution of women to environmental policy is largely ignored. Decision-making and policy formulation at all environmental levels, i.e., conservation, protection and rehabilitation and environmental management are more or less a male preserve. Women have been involved in promotion of appropriate energy technologies, primarily for rural population over the past 15 years. This article highlights the experience of working with rural people in seeking solutions for community energy needs through renewable environmentally friendly energy technologies.

Keywords: Sudan; Energy; Consumption patterns; Renewable energy potential; Sustainable development; Impacts on environment; Mitigations

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1. Introduction

Sudan is an agricultural country with fertile land, plenty of water resources, livestock, forestry resources, and agricultural residues. Energy is one of the key factors for the development of national economies in Sudan. An overview of the energy situation in Sudan is introduced with reference to the end uses and regional distribution. Energy sources are divided into two main types; conventional energy (biomass, petroleum products, and electricity); and non-conventional energy (solar, wind, hydro, etc.). Sudan possesses a relatively high abundance of sunshine, solar radiation, and moderate wind speeds, hydro, and biomass energy resources. Application of new and renewable sources of energy available in Sudan is now a major issue in the future energy strategic planning for the alternative to the fossil conventional energy to provide part of the local energy demand. Sudan is an important case study in the context of renewable energy. It has a long history of meeting its energy needs through renewables. Sudan's renewables portfolio is broad and diverse, due in part to the country's wide range of climates and landscapes. Like many of the African leaders in renewable energy utilisation, Sudan has a well-defined commitment to continue research, development, and implementation of new technologies. Sustainable low-carbon energy scenarios for the new century emphasise the untapped potential of renewable resources. Rural areas of Sudan can benefit from this transition. The increased availability of reliable and efficient energy services stimulates new development alternatives. It is concluded that renewable environmentally friendly energy must be encouraged, promoted, implemented, and demonstrated by full-scale plant especially for use in remote rural areas.

Climate change is a hot issue in world politics. The use of fossil fuel is seen as a cause of critical global warming. Long-term energy options currently considered include the

petroleum, electricity, and biomass. Sustainability is increasingly becoming an element of world politics, although there is not yet agreement on a clear definition and indicators are still not yet fully agreed upon that would effectively enable the establishment of the sustainable development, which is so eagerly sought. However, the snowball is rolling: the process of designing sustainable development has started, and it is only a matter of political will, negotiations and time for it to accelerate, hopefully in the right direction. The job is tough, and the variety of stakeholders involved in today's globalisation process makes the whole story even more interesting and challenging. And yet, globalisation and sustainable development are bound to become tautological. The goal of sustainability has different meanings and measures specific to various regions of the planet, each with their own economics, histories, and cultures. A pathway to sustainable development that is reasonable, achievable and hence natural in one country.

In developed countries, most investments in electricity generation have paid back their initial capital costs. Research and development of new electricity generation technologies are well under way, and these technologies hold good promise of achieving commercial feasibility. New investments in electricity generation have not been aggressively pursued in recent years. Rather, policies for existing energy infrastructures have included improved options for more sustainable electricity generation e.g., less pollution, higher fuel efficiency and life extension. However, are, at best, only interim solutions. Stakeholders interaction is essential to create a culture of sustainability, with educational, regulatory, economic, environmental and ethical dimensions that can have an impact on society overall. Such a culture of sustainability must be designed, managed and measured in ways compatible with societal attitudes towards risk, including changes in perspective over medium and long-term time horizons. Risk-related concepts play a large part in what technologies the public views as sustainable, whether it concerns potentially large accidents from electric generation technologies, greenhouse gas emissions, vulnerability to natural disasters, or decommissioning and site reclamation problems. Research and development costs and expected lead times related to electricity generation, also play a role in stakeholder positions and public attitudes [1].

There are increasing concerns but the sustainability of the energy sector, ranging from impacts of current operation to the choice of future options for system development. These concerns include such issues as health and safety, environmental emissions, use of energy and materials resources, regulated versus competitive markets, vulnerability of electrical energy networks, cost and equity issues among users of diverse size, and appropriate technology for the development and commercialisation of improved supply and end-use equipment. Such concerns span the geographic spectrum from local issues such as cost and siting, to regional issues like acid rain [2], state and national issues such as deregulation and social acceptance of competing technologies, and global issues such as climate change [3]. Decision-makers and planners in the energy sector must address these issues, and fit them into a broader framework of national and world energy and develop policies. The methodological framework needed to assist decision-makers can be generalised in part, because most of these problems share common elements, and can be characterised by their combination of: (1) complexity, (2) dispersed solutions, (3) finite resources, and (4) societal impacts. In the areas of power systems are planning, one of the most pressing problems that exemplifiers this combination of characteristics is the intersection between:

(a) the rapid liberalisation of energy industries driving short-term actions to maximise stakeholder values, and

(b) the possible restrictions on greenhouse gas emissions proposed to meet the problem of global climate change.

2. Solar energy

2.1. Solar radiation over Sudan

Solar radiation arriving on earth is the most fundamental renewable energy source in nature. It powers the bio-system, the ocean and atmospheric current system and affects the global climate. Reliable radiation information is needed to provide input data in modelling solar energy devices and a good database is required in the work of energy planners, engineers, and agricultural scientists. In general, it is not easy to design solar energy conversion systems when they have to be installed in remote locations. Firstly, in most cases, solar radiation measurements are not available for these sites. Secondly, the radiation nature of solar radiation makes difficult the computation of the size of such systems.

While solar energy data are recognised as very important, their acquisition is by no means straightforward. The measurement of solar radiation requires the use of costly equipment such as pyrheliometers and pyranometers. Consequently, adequate facilities are often not available in developing countries (Sudan is no exception) to mount viable monitoring programmes. This partly due to the equipment cost and also the cost of technical manpower. Several attempts have, however, been made to estimate solar radiation through the use of meteorological and other physical parameter in order to avoid the use of expensive network of measuring instruments.

The design and estimation of the performance of all solar energy systems require the knowledge of solar radiation data, which have been measured over a long period of time. The solar radiation measurements are very important in order to establish a complete solar map for Sudan. These data are not only useful for the country under consideration but also for many other countries. This is needed for two main reasons: (1) The possibility of plotting solar radiation maps for the whole world through the availability of the required data for all countries of the world, and (2) The manufacturers of solar devices require the knowledge of solar radiation data in the different locations. This is most important in order to design such devices to suit the climate and to open new markets accordingly.

Solar radiation data are not easily available for many countries. Many countries cannot afford the measurement equipments and techniques involved. The solar equipments needed for these purposes are expensive and require maintenance as well as frequent calibrations. Moreover, it is almost impossible to scan all the country and get reliable day-by-day solar radiation data. Therefore, this work is an effort to find out reliable methods for prediction of solar radiation data with minimum possible measurements.

For the sizing of a solar system using total solar radiation (flat plate thermal solar collector or photovoltaic (PV) modules), or to estimate its productivity, many engineers use daily or hourly solar irradiation data. But, in many cases as for instance mathematical simulation of solar energy processes, these values are not sufficient because they do not provide a precise idea of the different energy phenomena, which take place in the heart of the production system (inertia phenomenon, shadowing masks, etc.). For example, for the sizing of a stand-alone PV system, knowledge of the load is required and this load is

sometimes known with a time step interior to 1 h; it is then necessary to transform this load profile into hourly data, which leads to the loss of information.

The availability of data on solar radiation is a critical problem. Even in developed countries, very few weather stations have been recording detailed solar radiation data for a period of time long enough to have statistical significance, and Sudan is no exception. In various studies of solar energy systems (sizing, estimation of production), solar irradiation data collected is needed. The need for solar information is essential in the design and study of solar energy conversion devices. Other uses of such information include agricultural studies, meteorological forecasting, environment and energy conservation.

2.2. *Energy for solar water pumping*

In recent years, solar energy utilisation in various applications (both solar thermal and PVs) has increased significantly. Applications involving solar thermal energy include air and water heating whilst solar PV systems have been installed to provide electricity for households mainly in rural areas. In Sudan, several research institutions have initiated research at various stages on the applications of solar energy in various industrial processes [4,5]. However, the availability of monthly global solar radiation data required in solar thermal designs is very limited. The high cost of solar radiation equipment is still unaffordable by most institutions involved in solar energy research and development activities. Hence, adequate and relatively accurate solar radiation data are often not readily available in locations of interest. As a consequence, the solar systems installed often do not reflect the optimum designs.

More than 70% of Sudan's area is classified as arid, representing the rural and desert part, which lack electricity and water networks. The inhabitants of such areas obtain water from borehole wells by means of water pumps, which are driven by diesel engines (Table 1). The diesel motors are associated with maintenance problems, high running cost, and environmental pollution. Alternative methods are pumping by PV or wind systems.

The hydraulic energy required to deliver a volume of water is given by the formula:

$$E_{\mathrm{w}} = \rho_{\mathrm{w}} g V H, \tag{1}$$

where E_{w} is the required hydraulic energy (kWh day^{-1}), ρ_{w} the water density, g the gravitational acceleration (ms^{-1}), V the required volume of water (m^3 day^{-1}), and H the head of water (m).

Table 1
Specifications of pumps

Specifications	Site 1	Site 2	Site 3	Site 4
Pumping head (m)	79	67	63	62
Pumping rate (m^3 h^{-1})	7.4	6.2	7.1	7.1
Derated engine output (kW)	3.74	3.26	3.58	3.55
Full load fuel consumption (l h^{-1})	1.43	1.24	1.37	1.34
Estimated pump efficiency (%)	68	70	70	70
Fuel consumption factor (l m^{-3})	0.14	0.13	0.11	0.12
Engine loading (%)	63	50	41	48
Predicted fuel consumption (l h^{-1})	1.0	0.8	0.7	0.8
Predicted efficiency (%)	15	13	12	13

The solar array power required is given by

$$P_{sa} = E_w / E_{sr} \eta F, \tag{2}$$

where P_{sa} is the solar array power (kW$_p$), E_{sr} the average daily solar radiation (kWh m^{-2} day^{-1}), F the array mismatch factor, and η the daily subsystem efficiency.

Substituting Eq. (1) in Eq. (2), the following equation is obtained for the amount of water that can be pumped:

$$V = P_{sa} E_{sr} \eta F / \rho_w g H. \tag{3}$$

PV consists of 32 modules $P_{sa} = 1.6\,\mathrm{kW_p}$, $F = 0.85$, $\eta = 40\%$.

3. Efficient bio-energy use

3.1. Briquette

Charcoal stoves are very familiar to Sudanese society. As for the stove technology, the present charcoal stove can be used, and can be improved upon for better efficiency. This energy term will be of particular interest to both urban and rural households and all the income groups due to the simplicity, convenience, and lower air polluting characteristics. However, the market price of the fuel together with that of its end-use technology may not enhance its early high market penetration especially in the urban low income and rural households.

3.2. Improved cook stoves

Similar to other African countries, most wood energy users and suppliers in Sudan are women. Within the communities included in the Gender Resource Information and Development Institute (GRID) survey, women had the sole or at least the primary responsibility for gathering fuelwood, a task they performed two or three times a week. Additionally women were found to perform other household activities—cooking, water collection and childcare, and often had to travel with their babies and small children when collecting water or fuelwood. Most of this wood was harvested from forests and woodlands; and carried in shoulders or in back baskets. A typical load of wood weighed 10–20 kg. On average collecting wood for her family, carried 100–150 such loads per year. In ethnic communities where the division of labour was very strict, when women became in capacitated due to an illness or from childbirth, the security of the household's energy supply was threatened-evidence of the important role gender aspects play in wood energy management and planning in Sudan [6].

Women involved in income generating activities were more interested in energy saving stoves as a means of saving time and labour. These stoves are now being produced and marketed in Sudan, and training on how to construct the stoves is available. However, the women have not been completely satisfied with the stoves. Some complain that they are unable to use the stoves to prepare specific Sudanese recipes. Empirical studies have been shown that problems such as these could be avoided if women were more involved in all stages of the stove technology development processes. Local traditional stoves were tested, improved, invested, and commercially used in Sudan (traditional muddy stoves, bucket stoves and tin stoves). Also, prototypes were tried and tested in Sudan. Most urban

households burn charcoal on a traditional square ''Canun'' stove that has very low fuel-to-heat conversion efficiencies. Moreover, there are still many parts of the country where it is very difficult for women to become involved in income generating activities. The market opportunities that have been provided for some have had little effect on women living in less accessible rural areas. Poor transportation and communication infrastructures have limited rural women's ability to buy inputs and to sell their commodities.

More than 70% of the total Sudanese population lives in rural and isolated communities characterised by extreme poverty and power social; and economical activity. The unavailability and the acute shortages of the conventional energy supply (petroleum and electricity) to rural people forced them to use alternatives available energy sources like biomass [7]. This situation caused serious environmental degradation beside the poor unsatisfactory services of some basic needs such as: Food security, Water supply, Health care, and Communications.

The rural women must work extremely hard just to provide the essentials—food, water, firewood, etc. for their families. This heavy workload limits women's economic activities and girls education. The women living in poor rural areas are the ones most in need of labour saving options such as firewood plantations close to their homes and fuel-efficient stoves, but they lack the money and information to be able to invest in these options. Development efforts and resources from organisations and the government that are directed at poverty alleviation need to address these issues if they are to benefit poor women and their families [7].

Biomass is generally and erroneously regarded as a low status fuel and rarely finds its way into the energy statistics when, in fact, it should be considered as a renewable energy equivalent to fossil fuels. It offers considerable flexibility of fuel supply due to the range and diversity of fuels that can be produced. Biomass can be burnt directly or it can be converted into solid, gaseous and liquid fuels using conversion technologies such as fermentation to produce alcohols, bacterial digestion to produce biogas and gasification to produce a natural gasification to produce a natural gas substitute. Industrial, agricultural livestock and forest residues can be used as a biomass energy source, or energy crops such as trees and sugarcane can be grown specifically for conversion to energy. Total final consumption of biomass in developing countries is projected to continue to increase, rising from 825×10^6 tonnes of oil equivalent (Mtoe) in 1995 to 1071×10^6 Mtoe in 2020, although at a lower rate than population growth and a much lower rate than conventional energy use. The rate of growth of total biomass consumption is relatively low and is slowing down: it is projected to be 1.2% per annum between 1995 and 2020, 1.1% between 2000 and 2010 and 1% between 2010 and 2020. During the same periods, final consumption of conventional fuels is projected to grow at much faster rates (4.3%, 3.5%, and 3.1% per annum, respectively). As a result, the share of biomass in total final consumption will decline from 34% in 1995 to 22% in 2020. There are significant regional differences in the rates of growth and resulting shares [8].

Among the renewable energy sources, biomass seems one of the most interesting because of its share of the total energy consumption of Sudan is high at 87%, and the techniques for converting it to useful energy are not necessarily sophisticated. Implementation of biomass-based energy programmes will not, of course, be a definitive solution to the country's energy problem, but it will bring new insight for efficient energy use in the household sector, especially in rural areas where more than 70% of the populations live (25 million). The estimates are based in the recoverable energy potential from the main

agricultural residues, livestock farming wastes, forestry and wood processing residues, and municipal wastes.

Fuelwood, animal wastes, agricultural crop residues, and logging wastes have been used through direct burning in Sudan for many years. These sources are often called non-commercial energy sources, but in Sudan fuelwood is a tradable commodity since it is the primary fuel of rural areas and the urban poor section. Traditional fuels predominate in rural areas; almost all biomass energy is consumed in the household sector for heating, cleaning and cooking needs of rural people. Especially in the villages (households on the high plateau) the preparation of three stone fires is very attractive to the villagers. In this method, food and plant residues are put in a large boiler with water and cooked on a traditional stove at the outside the house for animal feed, because cooked food and plant residues are cheaper than flour and bran. Nevertheless, this method consumes much more fuelwood than the cooking on the stoves method. On the other hand, wood is the most practical fuel for serving a large number of people because the size of the batch of food is only limited by the volume of the pot and not by the size of the stove's burner. Fuelwood is also convenient for cooking of the meal of meat as a cutlet meatball and meat roasted on a revolving vertical spit (Table 2).

Special attention should, therefore, be given to reviewing forest resources, plantation programmes and the possibilities of substitution of fuelwood for commercial fuels or for other fuels such as biogas. The main sources of fuelwood supply in the country can be broadly be grouped into two main categories, i.e., forest sources (forests under the control of forest departments) and non-forest sources (private farmland and wild lands). Women, assisted by children almost always, perform the gathering of fuelwood in rural areas of developing countries. As fuelwood becomes scarce, which is the case in many parts of the world, the collection time has increased and although men do not perceive it, this has many undesirable consequences, which can be clearly seen in many rural region of Sudan. Women have less time for their other important functions, such as cooking, washing, water collection, and child rearing which may affect the nutrition and health of the entire family. Wood energy is, for many countries, one of the few locally available sources of energy, which they can afford. Its substitution by imported fossil fuels, as has often been carelessly recommended, should attentively be evaluated to avoid undesirable political, economic and social consequences.

3.3. *Biogas*

Presently, Sudan uses a significant amount of kerosene, diesel, firewood, and charcoal for cooking in many rural areas. Biogas technology was introduced to Sudan in mid 1970s

Table 2
Annual biomass energy consumption patterns in Sudan ($10^3\,m^3$) [9]

Sector	Firewood	Charcoal	Total	Percent (%)
Residential	6148	6071	12,219	88.5
Industrial	1050	12	1062	7.7
Commercial	32	284	316	2.3
Quranic schools	209	0	209	1.5
Total	7439	6367	13,806	
Percent (%)	54	46		100.0

when GTZ designed a unit as part of a project for water hyacinth control in central Sudan. Anaerobic digesters producing biogas (methane) offer a sustainable alternative fuel for cooking, and lighting that is appropriate and economic in rural areas. In Sudan, there are currently over 200 installed biogas units, covering a wide range of scales appropriate to family, community, or industrial uses. The agricultural residues and animal wastes are the main sources of feedstock for larger scale biogas plants.

There are in practice two main types of biogas plant that have been developed in Sudan; the fixed dome digester, which is commonly called the Chinese digester (120 units each with volumes 7–15 m^3). The floating gasholder known as the Indian digester (80 units each with volumes 5–10 m^3). The solid waste from biogas plants adds economic value by providing valuable fertilizer [4].

Biogas technology cannot only provide fuel, but is also important for comprehensive utilisation of biomass forestry, animal husbandry, fishery, agricultural economy, protecting the environment, realising agricultural recycling, as well as improving the sanitary conditions, in rural areas. The introduction of biogas technology on wide scale has implications for macro planning such as the allocation of government investment and effects on the balance of payments. Factors that determine the rate of acceptance of biogas plants, such as credit facilities and technical backup services, are likely to have to be planned as part of general macro-policy, as do the allocation of research and development funds [4].

3.4. Improved forest and tree management

Another area in which rural energy availability could be secured where woody fuels have become scarce, are the improvements of traditional cookers and ovens to raise the efficiency of fuel saving. Also, by planting fast growing trees to provide a constant fuel supply. The energy development is essential and economically important since it will eventually lead to better standards of living, people's settlement, and self sufficient in the following:

- Food and water supplies.
- Better services in education and health care.
- Good communication modes.

The aim of any modern biomass energy systems must be:

- To maximise yields with minimum inputs.
- Utilisation and selection of adequate plant materials and processes.
- Optimum use of land, water, and fertiliser.
- Create an adequate infrastructure and strong R & D base.

Direct burning of fuel-wood and crop residues constitute the main usage of Sudan biomass, as is the case with many developing countries. However, the direct burning of biomass in an inefficient manner causes economic loss and adversely affects human health. In order to address the problem of inefficiency, research centres around the country are investigating the viability of converting the resource to a more useful form, namely solid briquettes and fuel gas. Briquetting is the formation of a char (an energy-dense solid fuel

source) from otherwise wasted agricultural and forestry residues. One of the disadvantages of wood fuel is that it is bulky and therefore requires the transportation of large volumes. Briquette formation allows for a more energy-dense fuel to be delivered, thus reducing the transportation cost and making the resource more competitive. It also adds some uniformity, which makes the fuel more compatible with systems that are sensitive to the specific fuel input [3].

To avoid resource depletion, Sudan is currently undergoing a reforestation programme of 1.05×10^6 ha. Biomass residues are more economically exploitable and more environmentally benign than dedicated biomass resources [2]. There exists a variety of readily available sources in Sudan, including agricultural residues such as sugar cane bagasse, and molasses, cotton stalks, groundnut shells, tree/forest residues, aquatic weeds, and various animal wastes as shown in Table 2.

4. Energy efficiency and renewable energy for the future

The world population is rising rapidly, notably in the developing countries. Historical trends suggest that increased annual energy use per capita is a good surrogate for the standard of living factors, which promote a decrease in population growth rate. If these trends continue, the stabilisation of the world's population will require the increased use of all sources of energy as cheap oil and gas are depleted. The improved efficiency of energy use and renewable energy sources will be essential to stabilising population, while providing a decent standard all over the world.

Today, renewable energy is some 13% of the world annual energy use of about 9×10^9 tonnes of oil equivalent (Mtoe/a; 1 toe = 42 GJ). Fossil fuels account for the bulk, about 80%, of the energy use. In the future, it is postulated that these roles will change as energy demand rises and cheap oil and gas are depleted; even without consideration of global warming effects. The changes will be driven mainly by the developing areas, which have relatively less of the fossil fuel reserves, but have a substantial potential to deploy renewable energies.

There is a need to move towards a sustainable energy policy with the objectives of environmental protection, sound natural resource management and energy security. Opportunities exist for the increased development of renewable energy and energy efficiency through regulation, changes to institutional and economic arrangements, and through liberalisation of the energy market, which offers the potential for the development of energy service companies and a market for green electricity.

Friends of the Earth have been one of the leading environmental groups campaigning in support of renewable energy and energy efficiency over the last two decades. We are campaigning for sustainable development, which has been defined as development, which meets present needs without compromising the ability of future generation to meet their needs.

Energy efficiency is the most cost-effective way of cutting carbon dioxide emissions and improvements to households and businesses can have many additional social, economic and health benefits—warmer and healthier homes, lower fuel bills and company running costs, and jobs. Sudan wastes 20% of its fossil fuel and electricity use, implying that it would be cost-effective to cut $10 million a year off our collective fuel bill and reduce CO_2 emissions by some 120 million tonnes. Yet lack of good information and advice on energy

saving, along with the capital to finance energy efficiency improvements, means that the huge potential for reducing energy demand is not being realised.

5. Sustainable development

There is an unmistakable link between energy and sustainable human development. Energy is not an end in itself, but an essential tool to facilitate social and economic activities. Thus, the lack of available energy services correlates closely with many challenges of sustainable development, such as poverty alleviation, the advancement of women, protection of the environment, and jobs creation. Emphasis on institution-building and enhanced policy dialogue is necessary to create the social, economic, and politically enabling conditions for a transition to a more sustainable future. On the other hand, renewable energy technologies are a promising option, with a potentially large impact for Sudan as with other developing countries, where the current levels of energy services are low. Biomass accounts for about one-third of all energy in developing countries as a whole, and nearly 96% in some of least developed countries.

The local depletion of wood resources, and the corresponding increase in the distances necessary to collect this biomass, are national concerns. However, some rural communities were affected before others, due mainly to the agro-ecological characteristics of their areas. In response to the increased drudgery and time spent in sourcing energy supplies, government departments, NGOs, and other bilateral and multilateral agencies have promoted both alternative and improved energy conversion technologies for rural communities.

The sustainable livelihood framework is a useful analytical structure that can accommodate the complexity of poor people's lives, and the ways in which external interventions can support them. The framework is essentially a two-part feedback loop, conceptualising the strengths and weaknesses of the poor, and confronting these with the mechanisms used by outsiders to combat (or support!) poverty. The essential link between the two is that of influence and access. The training manuals seek to provide support for this vital interactive channel for understanding, equity and communication.

In remote communities, energy technology is often implemented solely for poverty reduction. However, from a user's point view, the use of modern energy requires monetary exchange. Thus, success depends upon the ability of users to pay for services, a requirement that is often in conflict with the very motive behind the development. Energy development from its outset must be planned with a strategy of how users will meet these costs. Furthermore, because users do not have capital to develop income-generating activities, planners should implement such activities in parallel. In this sense, energy development must be considered as a part of an integrated economic development strategy. On scales from local to global to ensure a better quality of life for all people, now and in the future, through the implementation of sustainable development initiatives that promote:

- Environmental integrity.
- Economic efficiency that helps to eliminate inequalities.
- Social equity for all, regardless of race, gender, disability or creed.
- Democracy.
- Food and water security.

- Effective education for environmentally and socially responsible citizenship, and
- Mutual understanding between people.

Climate change scenarios sources of uncertainty:

Factors influencing the future climate are:

- The future emission rates of greenhouse gases (GHGs).
- The effect of these emissions on GHGs concentrations in the atmosphere.
- The effect of this increase in concentration on the energy balance of the atmosphere, and
- The effect of this change in energy balance on global and regional climate.

6. Synthesis of the renewable energy

Although the overall impact of renewables has been necessarily low, the experience has clearly demonstrated their potential as sustainable energy alternatives. There has been substantial learning in disseminating and managing various technologies on account of:

- Scale: with increasing numbers, teething problems have been overcome and better knowledge has been gained in different aspects related to planning, implementation, operation and maintenance.
- Indigenisation: through joint ventures with international industry, the technology transfer process has been facilitated, helping in developing local production capacities.
- Infrastructure: a strong infrastructure has been created over the years to provide the technical, operational and managerial support to intervention programmes. This includes research institutions, training agencies, NGOs, financial intermediaries, etc.
- Diverse strategies: though the whole renewable energy programme started with the same technology push approach, diversification occurred over a period of time in terms of strategies and to promote different technologies according to market conditions (Table 3).

7. Present status of rural energy

Rural energy consumption in less developed countries (LDCs) constitutes majority of their total national energy use. The social and economic costs of insufficient supplies of household fuels are high and rising rapidly. According to UNDP and World Bank estimates based on investigations in 15 LDCs, household energy consumption accounts for 30–95% of total energy use, much higher than the 25–30% for the developed countries [10]. Furthermore, in many developing countries, biomass, especially firewood, is the principal rural energy resource for household use, and firewood has been identified as one of the most significant causes of forest decline. Rural energy is fundamental to the development of the rural economy, and is an important component of the national energy.

In the past two decades, the main efforts in rural energy development have focused on the popularisation of fuel-saving stoves and commercial energy, integrated utilisation of biomass, and wide use of renewable energy technologies. Improving the thermal efficiency

Table 3
Diversity of promotion strategies

Technology	Strategy	Key change agents	Mechanisms
Power generation			
Wind	Government-enabled market pull	Private sector State utilities Manufacturers	Fiscal incentives Multilateral finance
Small-hydro	Government-enabled market pull	Private sector State utilities Manufacturers	Fiscal incentives Multilateral finance
Biomass cogeneration	Government-enabled market pull	Private sector	Fiscal incentives
Solar PV	Combination of demonstration and pull	Government NGOs Intermediaries Manufacturers	Low interest finance Flexible loan serving Maintenance by intermediaries
Thermal energy			
Biogas	Technology push	Government NGOs Turnkey workers	Cash subsidy Training support
Improved stoves	Technology push	Government NGOs Self-employed workers	Cash subsidy Training support
Solar cookers	Push in the beginning Currently market pull	Government Manufacturers	Mini-subsidy Segmentation with focus on small towns and cities
Solar water heaters	Push in the beginning Currently market pull	Government Manufacturers	Segmentation with focus on industrial systems

of fuel stoves is one of the environment and for saving firewood, because most household energy in rural areas is in the form of firewood and straw. Biomass gasification technology has also been put into practical use. Recently, there were some illustrative biomass gasification stations operating.

Small hydropower has the advantages of low investment and short period of construction. Therefore, it is an effective way to rural electrification. In addition, small reservoirs and dams for hydropower would also benefit agricultural production and increase the protection against natural disasters.

Sudan has abundant solar energy resources due to the clear sky. The favourable climatic conditions have brought about a rapid development of solar energy technology in the past three decades (solar water heaters, PV for lighting, solar cookers, etc.). The low income of farmers and high cost of PV devices make the popularisation of PV systems for lighting difficulty.

8. Problems and difficulties in rural energy development

8.1. Imbalance in rural energy development

Due to the difference in economic conditions in different areas, the development of rural energy is considerably imbalanced. The main challenge to energy policymakers in the 21st century is how to develop and manage adequate, affordable and reliable energy services in

a sustainable manner to fuel social and economic development. Generally, future rural energy will be oriented towards green energy, and the future development of rural energy will concentrate on biogas, small hydropower, solar energy, and wind power.

8.2. Insufficient investment in development of rural energy

Current rural energy relies mainly on charcoal, firewood and green energies, such as electricity and biogas. The bad economic situation leads to considerable difficulty in the development of rural energy, and farmers in remote areas still prefer "free firewood" for their cooking due to low income. Hence, further development of rural energy needs significant financial support from the government at various levels. Although the work of rebuilding traditional stoves has been almost finished, most of the rebuilt fuel-saving stoves have a thermal efficiency less than 20%.

8.3. Excessive dependence on forests for rural energy

Currently, energy for rural household use comes mainly from burning of firewood. The annual consumption of forests is 1.96 Mm^3, and of this 0.65 Mm^3 is as firewood. To some extent, this pattern of energy consumption has led to environmental damage such as water and soil loss, decrease in forest cover, and air pollution. The excessive use of firewood from forests for rural energy would cause damage to sightseeing resorts, make animals lose their habitats, and lead to the extinction of some endangered plants. The future development of rural energy should be aimed to completely changing the current pattern of energy consumption, fully utilising abundant resources of hydropower, biomass, solar and wind energy, promoting economic growth through the development of rural energy and integrated utilisation of biomass.

9. Energy in agriculture

Energy use in agricultural production has become more intensive due to the use of fossil fuel, chemical fertilisers, pesticides, machinery and electricity to provide substantial increases in food production. However, more intensive energy use has brought some important in terms of sustainable agricultural production. The energy ratios in agricultural production are closely related with production techniques, quantity of inputs used by producers and yield level of crops along with environmental factors such as soil and climate. Therefore, there is a range of energy input and output relationships for the same crop depending on the region.

Energy management should be considered an important field in terms of efficient, sustainable and economical use of energy. Energy use in cotton production is not efficient and detrimental to the environment due to mainly excess input use. Therefore, reducing these inputs would provide more efficient machinery use, and fertiliser, aided by removal of the fertilised subsidy. Furthermore, integrated pest control techniques should be put in practice widely to improve pesticide use. It can be expected that all these measurements would be useful not only for reducing negative effects to environment, human health, maintaining sustainability and decreasing production costs, but also for providing higher energy use efficiency.

Cotton produced is considered to be a fundamental source of material for the cotton gin industry processing it for fibre for the textile industry and oil and animal feed industry from seed. Cotton production creates an income source for many families, as it is an important source of employment in the country. The most important cost items were labour, machinery costs, land rent and pesticide costs. Large forms were more successful in energy productivity, use efficiency and economic performance.

10. The future

(1) In most of the developing countries, the governments acknowledge that, renewable energy can resolve many pressing problems. Yet, the matter stops at this level "Acknowledgement". Much more is needed, like laws regulating and encouraging business, tax concessions, both to investors and customers, and most of all, a sustained, coordinated and well-planned official publicity campaign to enlight, inform and educate the public at a large.
(2) To avoid the problems of fuel altogether (uncertain availability and skyrocketing prices), and minimise spare-parts, solar and wind pumps are proposed to replace diesel engines in the predominant irrigation areas.
(3) Local manufacture, whenever possible, is to be emphasised to avail renewable energy devices since limited funds are the main constraints in commercialisation and dissemination of the technology. Low cost devices as well as reliable devices have to be provided.
(4) Embarking on conservation energy and reduction of pollution of environment to be undertaken without delay:
    - To save on fossil fuel for premium users/export.
    - To accelerate development of new and/or remote lands otherwise deprived of conventional energy sources.
    - As a preventive measure against shortage of future energy supply against prospective national energy demand.
(5) Launching of public awareness campaigns among investor's particularly small-scale entrepreneurs and end users of renewable energy technologies to highlight the importance and benefits of renewables.
(6) To direct Sudan resources away from feeding wars and the arms industry towards real development, this will serve the noble ends of peace and progress.
(7) The energy crisis is a national issue and not only a concern of the energy sector, and the country has to learn to live with the crisis for a long period, and develop policies, institutions and manpower for longer term, more effective solutions.
(8) To invest in research and development through the existing specialised bodies e.g., Energy Research Institute (ERI).
(9) To encourage co-operation between nations, a fact which will be much easier in this era of information and the communications revolution.
(10) Government should give incentives to encourage the household sector to use renewable energy technologies instead of conventional energy.
(11) Promotion research and development, demonstration and adaptation of renewable energy resources (solar, wind, biomass, and mini-hydro, etc.) amongst national, regional, and international organisations which seek clean, safe, and abundant energy sources.

(12) Execute joint investments between the private sector and the financing entities to disseminate the renewables with technical support from the research and development entities.
(13) Promotion the general acceptance of renewable energy strategies by supporting comprehensive economic energy analysis taking account of environmental benefit.
(14) Availing of training opportunities to personnel at different levels in donor countries and other developing countries to make use of their wide experience in application and commercialisation of renewable energy technologies.
(15) To encourage the private sector to assemble, install, repair and manufacture renewable energy devices via investment encouragement, more flexible licensing procedures.

11. Conclusions

Air pollution from motor vehicles, electricity generation plants, industry, and other sources natural and man-made, can harm human health, injure crops and forests, damage building materials, and impair visibility. Public awareness and concern about the problems associated with reduced air quality have increased in recent years. Nevertheless, there still remains considerable uncertainty about both the severity and the valuation of these impacts. The valuation of environmental damages can play an important role in establishing environmental policy and regulatory standards, and can provide guidance in targeting mitigation efforts. In order to achieve environmental objectives at least cost, policy-makers and managers need to balance the relevant social costs and benefits.

The mitigation strategy of the country should be based primarily ongoing governmental programmes, which have originally been launched for other purposes, but may contribute to a relevant reduction of greenhouse gas emissions (energy-saving and afforestation programmes). Therefore, the main fields of emission mitigation will be the energy and the forestry sectors. The main reasons are as follows:

- The overall energy efficiency is far lower than that of the industrialised market economies. The efficiency on both the demands and the supply side have to be increased even in the short run. As far as the supply side is concerned, restructuring of the power plant system is unavoidable, since many plants are old.
- Traditionally, the forestry sector is highly developed and there is enough land even for a larger afforestation programme.

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